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EVALUATION OF WATER RECLAMATION SYSTEMS AND
ANALYSIS OF RECOVERED WATER FOR HUMAN CONSUMPTION

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Foreword

This research study was initiated by the Biotechnology Branch, Life Support Division, Biomedical Laboratory, Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio. The study was conducted in support of project 6373, "Equipment for Life Support in Aerospace," and task 637304, "Waste Recovery and Utilization." The program was under the supervision of C. A. Metzger. Principal investigator was Albert B. Hearld with technical support provided by Master Sergeant Bobby G. McMullen. Additional support was provided by Staff Sergeant Carl Gailey and Master Sergeant Walter Bigelow.

The analytical data referenced was furnished under Contract DO (33-657)-63-377 by the Robert A. Taft Sanitary Engineering Center (U. S. Public Health Service), Cincinnati, Ohio. Robert C. Kroner was in charge of the General Laboratory Services, Water Quality Section, which performed the analyses.

All of the water recovery systems discussed in this report were developed either by the Aerospace Medical Research Laboratories or on Government contracts.

This technical report has been reviewed and is approved.

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory
Aerospace Medical Research Laboratories

Abstract

Analyses were made of water recovered from human urine and from atmospheric condensate collected during manned tests inside a sealed chamber. Data on more than 200 samples were prepared for comparison with that of distilled water and tap water and with U. S. Public Health Standards for drinking water. Most of the samples were suitable for human consumption. Candidate systems for recovering potable water from urine were evaluated. Thermoelectric, eleetrodialysis, and vapor compression water reclamation deviees were determined to be suitable for use during extended aerospace missions.

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SECTION I.

Introduction

Since 1958, the Aerospace Medical Research Laboratories has been engaged in the study of techniques that have been proposed for recovering potable water from human urine, wash waters, and dehumidification water during earth-orbiting aerospace missions. The study has resulted in an evaluation of the techniques and in the testing of hardware which incorporate some of the techniques. The study is far from complete and will be continued with a more comprehensive evaluation and testing of those systems that are potentially most suitable for aerospace application.

Objectives of this program were: (1) to determine the quality of water recovered from human urine and dehumidification water with off-the-shelf equipment and with devices designed specifically for demonstrating water recovery techniques; (2) to ascertain the changes that occur in the recovered water when the pretreatment, method of processing, and/or posttreatment are altered; (3) to evaluate existing recovery systems for aerospace application and to select for further study the systems having the greatest potential; and (4) to provide industry and other agencies with data that would be of value in future development efforts and in studies of water quality, i.e., the relation between pH and COD or the chloride content of water recovered from urine by vapor distillation and by compression distillation.

SECTION II.

System Evaluation

TECHNIQUES

The techniques used for reclaiming the water are listed below and are identified by the abbreviations shown in the process column of the analytical data sheets, tables Ia-Ij.

VD – Vacuum Distillation
VC – Vapor Compression
E – Electrolysis
UF – Ultrafiltration
MP – Membrane Permeation
ED – Electrodialysis
UFC – Unfiltered Condensate
FC – Filtered Condensate
TE – Thermoelectric Distillation
F Cell – Fuel Cell

Data on distilled water (DW) and tap water (TW) are included for comparison with the data on the recovered water, especially that recovered from urine. The distilled water was purchased locally. The tap water was drawn from the Wright-Patterson Air Force Base water system.

SYSTEM OPERATION

Descriptions of the systems used to illustrate the techniques follow.

Vapor Compression – Two vapor compression water recovery systems were evaluated. One Model MR 08-082, was procured from Mechanics Research Division, General American Transportation Corporation, Niles, Illinois (ref 1). The vapor compression system (ref 2) was procured from General Dynamics/Electric Boat, Groton, Connecticut. An artist's concept of the MR 08-082 system is shown in figure 1. A schema of the evaporator/condenser (Electric Boat system) is shown in figure 2.

In both systems the water in the urine is evaporated under reduced pressures. The vapor is fed through a compressor into a condenser where the reclaimed product is collected. That latent heat rejected during the condensation is transferred back to the evaporator for reuse in vaporizing more water. Heat from an electric motor and/or from a heating coil is used to speed the evaporation and to replace heat lost to the surrounding atmosphere.

Vacuum Distillation – This system consists of a boiler in which urine is evaporated under reduced pressure. The vapors are drawn into a condenser and the product water collected is drained to a reservoir. The vapors are caused to pass through activated charcoal and/or a microporous glass fiber cloth. An excellent description of a typical vacuum distillation apparatus is contained in reference 3.

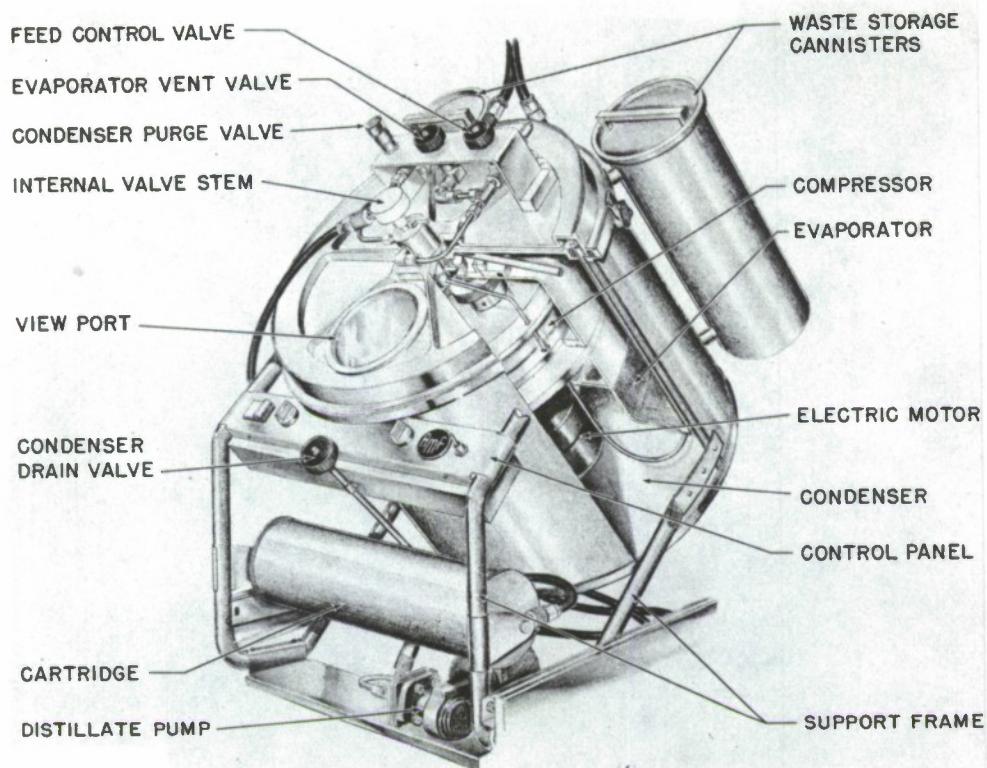


Figure 1. Vapor Compression System

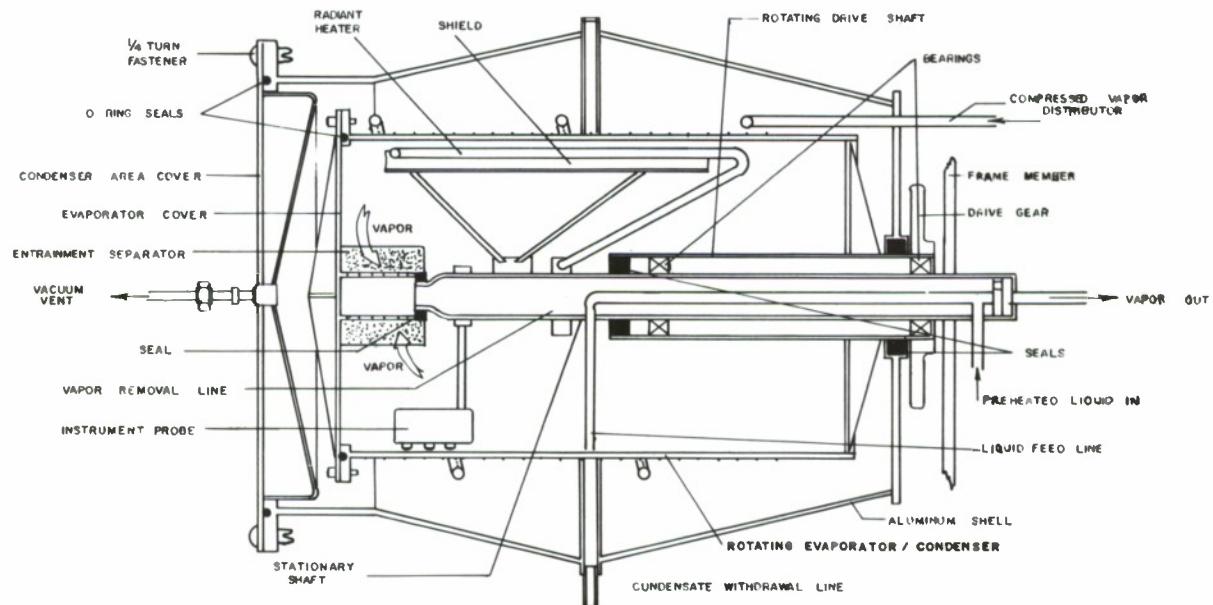


Figure 2. Evaporator/Condenser

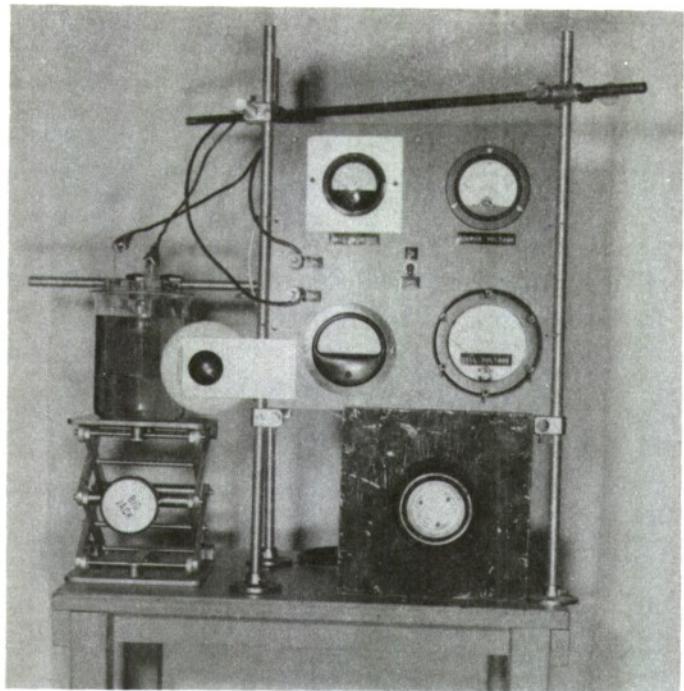


Figure 3. Electrolysis System

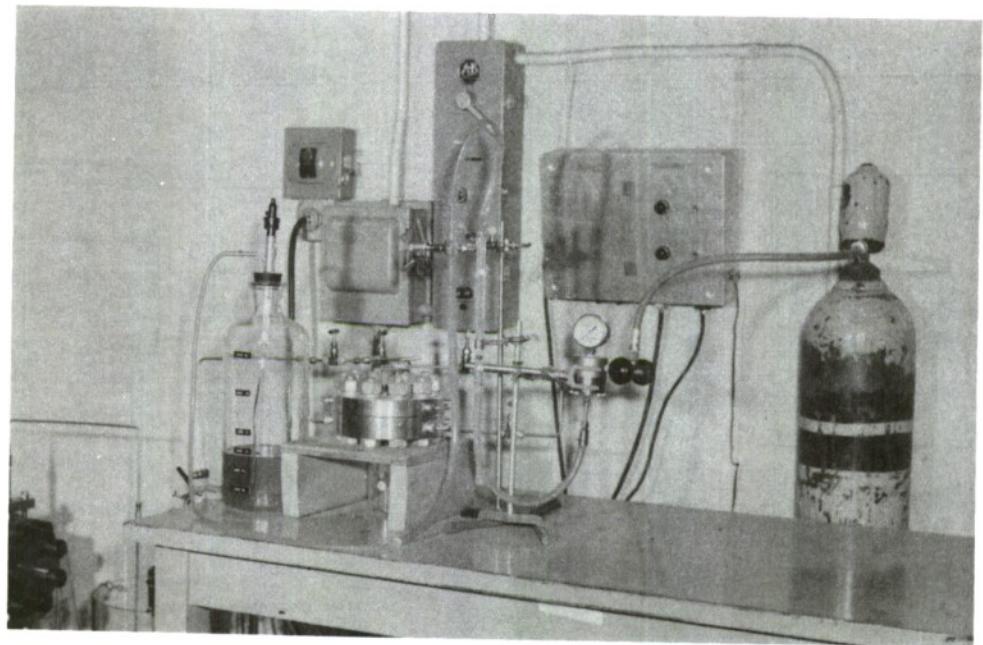


Figure 4. Ultrafiltration System

Electrolysis — the system used is shown in figure 3. A d-c current is passed through the urine from one platinum electrode to another. The chlorine produced at the anode reacts with the sodium hydroxide formed at the cathode and the hypochlorite formed decomposes the urea and other organics in the urine. The process lowers the pH of the recovered water and bacterial growth is eliminated.

Ultrafiltration — Urine that has been pretreated to remove urea and calcium is circulated over a membrane under a pressure greater than the osmotic pressure of the urine. Water passing

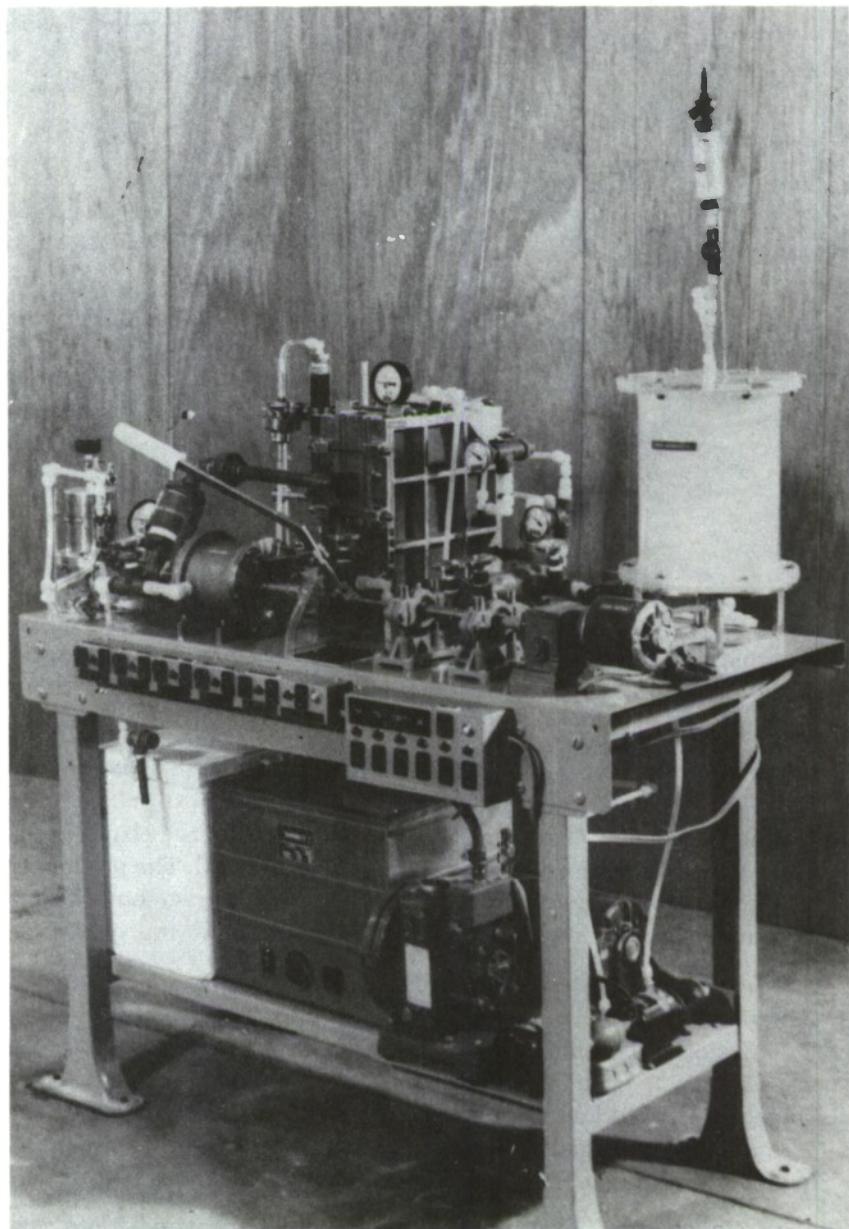


Figure 5. Membrane Permeation System

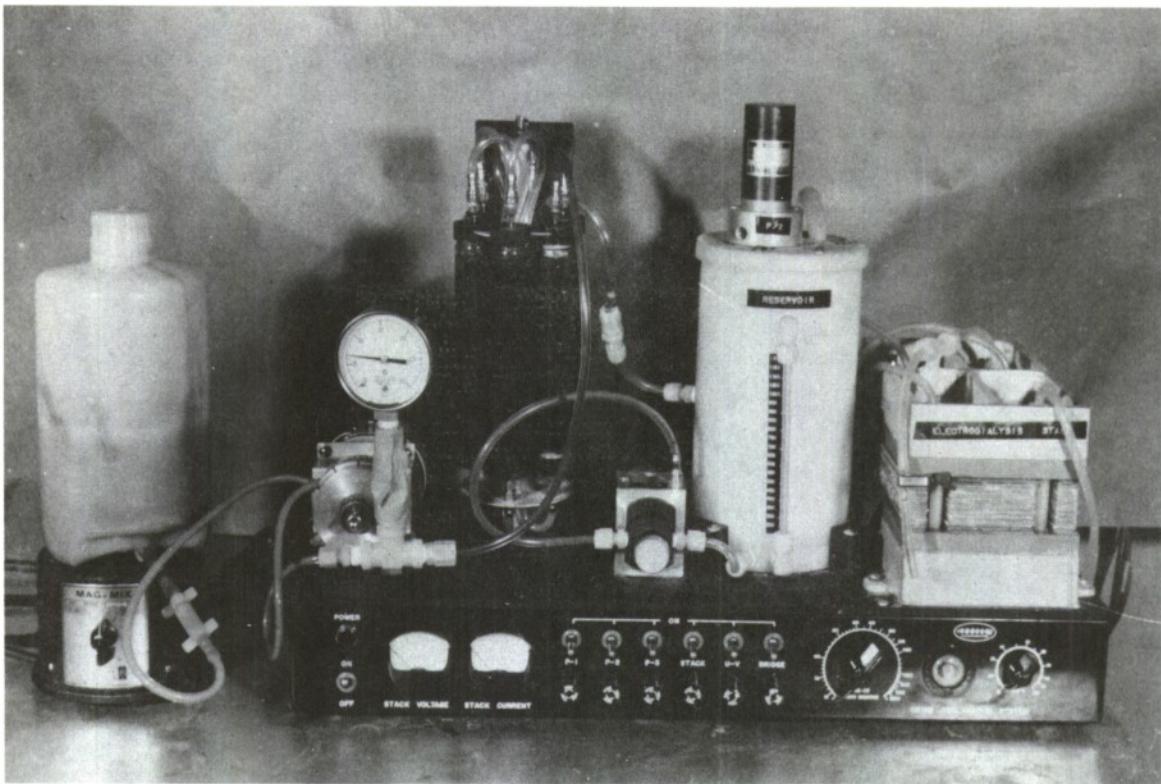


Figure 6. Electrodialysis System

out of the urine through the membrane is collected. The process is described in references 4, 5, 6, and 7. The ultrafiltration unit was procured from Radiations Applications, Incorporated, and is shown in figure 4.

Membrane Permeation — Hot urine is circulated through a permeator where the urine flows across two selectively permeable membranes. Water from the urine permeates the membranes and evaporates into a vacuum chamber. The vapor flows from the chamber through an ion exchange resin into a condenser where the product water is collected. The product is then pumped through a charcoal filter and a 0.45-micron (pore size) filter to a storage tank. The permeation system (ref 8) was procured from Ionics, Incorporated. Figure 5 shows the system.

Electrodialysis — This system (refs. 9 and 10) is shown in figure 6 and was procured from Ionics, Incorporated. Urine pretreated to precipitate a portion of the calcium and urea is pumped through a series of carbon filters into a reservoir from which it is circulated through a stack. The stack consists of compartments separated by alternating anion permeable and cation permeable ion exchange membranes and is located between a pair of electrodes. A d-c current passed through the stack results in the formation of two streams — a waste brine stream and a dilute or potable water stream. The pretreatment used consisted of silver nitrate plus oxalic acid in distilled water.

Filtered Condensate — Unless otherwise stated, the condensate was collected inside the AMRL Life Support Systems Evaluator during confinement studies involving four men for periods

of up to 28 days. All condensate was condensed from the atmosphere on a finned aluminum heat exchanger and drained to a sample bottle or pumped through one or more filters to a sample bottle. The samples were then submitted for analysis. Figure 7 is a schematic of one system used.

Unfiltered Condensate — All unfiltered condensate was collected inside the AMRL Evaluator and was submitted for analysis without being processed in any manner.

Thermoelectric Distillation — Urine is evaporated under reduced pressure and at a temperature of approximately 104 F (40 C). The resultant water vapor migrates to a series of condensers where it is condensed. The latent heat of condensation is thermoelectrically pumped back to the boiler for reuse. The product water flows from the condensers through a charcoal filter into a potable water storage tank. A schematic of the main assembly of the thermoelectric unit is shown in figure 8. An external view of the still is shown in figure 9. The thermoelectric distillation device is described in reference 17.

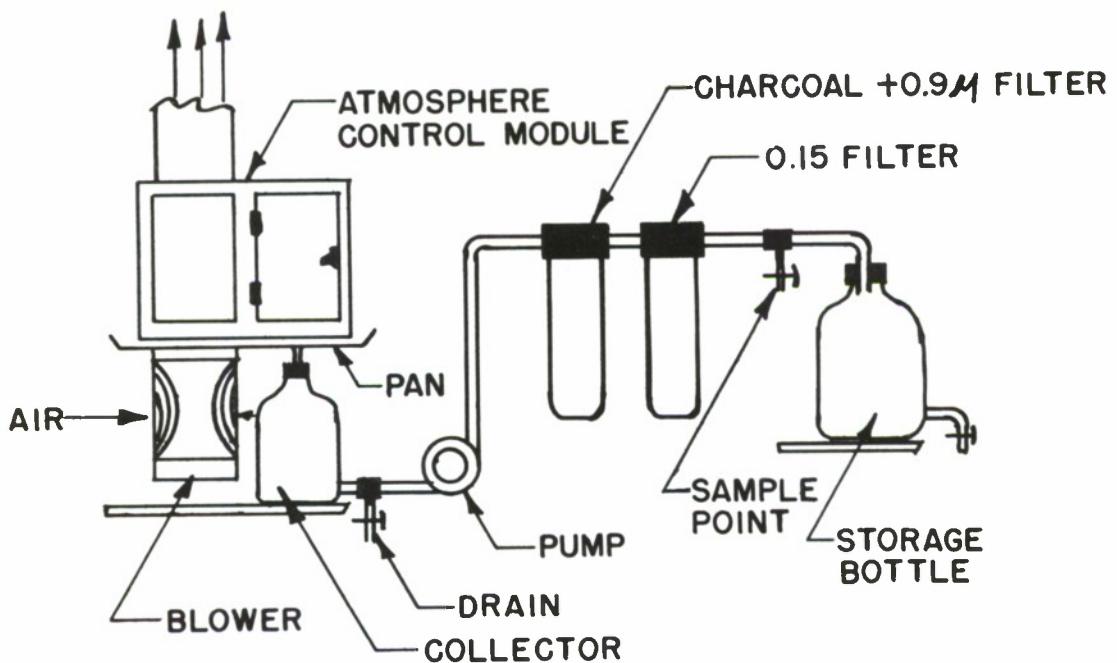


Figure 7. Dehumidification System

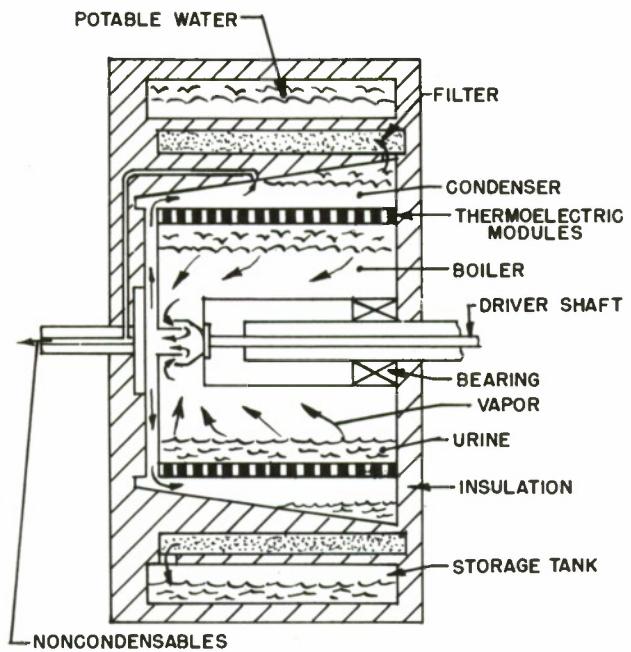


Figure 8. Main Assembly — Thermoelectric Unit

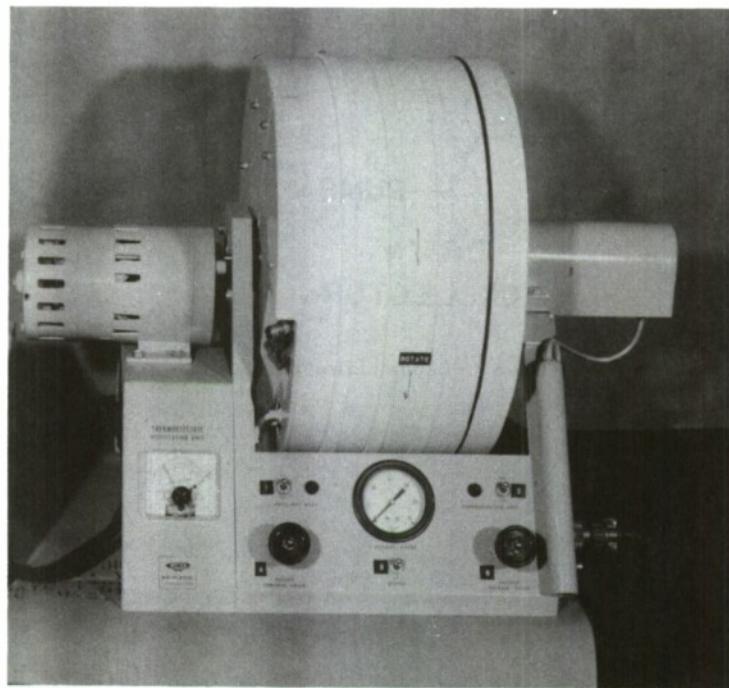


Figure 9. Thermoelectric Still

SECTION III.

Sampling and Results

More than 200 samples of water were recovered and submitted to Taft Sanitary Engineering Center (TC) for analyses. The processing varied — often from sample to sample. These differences are noted in the discussion of the samples which is contained herein. The analytical data were grouped, where convenient, in tables so as to illustrate one recovery technique. This grouping permits the data to be readily compared with the U. S. Public Health Standards for drinking water and with data on water reclamation by several techniques.

Following are the techniques used:

VAPOR COMPRESSION — See table Ia.

All samples were recovered by means of the Model 08-082 vapor compression distillation unit procured from MRD Division, General American Transportation Corporation. Unless otherwise specified, the recovered water was pumped through the filters at approximately 2 gallons per hour. Three to 4 liters of urine were processed for each sample.

Data on methods of processing follow:

Sample 1 — The urine was pretreated with one HTH (Hypochlorite 70% Cl tablet) and 10 drops of Antifoam B (Dow Corning). The water recovered was pumped through a 3½-inch inside diameter column containing 1130 grams of Hydrodarco activated carbon, 260 grams of Dowex 50W-X10 cation exchange resin, and a 1-inch thick glass wool filter.

Samples 2 and 3 — Processed same as sample 1 except that the urine was pretreated with 10 grams merthiolate per liter of urine in lieu of the HTH tablet.

Samples 4-7 — The urine was pretreated with merthiolate as in samples 2 and 3. The recovered water, however, was pumped up through a 4-inch diameter carbon (Nuchar C-190) column consisting of 3 inches of coarse carbon plus 12 inches of fine carbon plus 3 inches of coarse carbon at approximately ¼-gal. per minute.

Samples 10, 11, 12, and 14 — Untreated urine, with 10 drops of Antifoam B added to prevent foaming, was processed. The residue from samples 10, 11, and 12 was left inside the evaporator. All water recovered was pumped through a 0.15-micron* filter that was later found to be defective.

Samples 15-17 — The evaporator and condenser were cleaned and flushed with distilled water. A new evaporator liner was installed and two operations to flush the machine were made with a mixture of distilled water and benzalkonium chloride (BAC). The residue from the flush was left in the evaporator. The urine processed was pretreated with 10 grams of trimethylol nitromethane and ten drops of Antifoam B were added to prevent foaming. The product was pumped through a 0.15-micron filter.

Samples 18 and 19 — The machine was thoroughly scrubbed and flushed. A new evaporator liner was installed and the machine sterilized with cryoxide gas at ½ psig for 5½ hours then flushed for 16 hours with air passed through a sterilized filter. Four liters of sterile injection water were processed. For sample 18, the product was drawn directly from the machine. For sample 19, the water was pumped through the 0.15-micron filter used for samples 15-17.

*Nominal pore opening.

Sample 20 — Urine pretreated with 10 grams of trimethylol nitromethane and 10 drops of Antifoam B was processed on the residue left in the evaporator from samples 18 and 19. The recovered water was pumped through the filter used for samples 15-19.

Sample 25 — Urine with 10 drops of Antifoam B, was processed. The recovered water was drawn directly from the machine. Approximately 1 liter of water was recovered. This was not enough for the spectrographic tests.

Sample 32 — Urine with no additives was processed with the plastic evaporator liner removed from the machine. The sample was drawn directly from the machine.

MISCELLANEOUS TECHNIQUES — See table 1b.

Vapor compression, electrolysis, ultrafiltration, membrane permeation, and electrodialysis were employed in the recovery of the samples listed on table 1b. Data on the individual processings follow:

Sample 13 (Vapor Compression) — Approximately 2500 ml of urine with one HTH-hypochlorite tablet 70% Cl added was processed in a unit procured from General Dynamics/Electric Boat (EB). The distillate was filtered through S&S #595 analytical paper to remove debris from the machine then through a sterilized 0.15-micron filter.

Sample 22 (Electrolysis) — The sample was recovered by passing a d-c current (2 amperes) through a 1-liter beaker filled with untreated urine. A platinum plate (+) and a platinum gauze (-) were used as the electrodes. The urine was cooled by means of a water bath into which the beaker was placed. Six volts were applied to the electrodes. The electrolyzed product was filtered through S&S #595 paper.

Sample 23 (Ultrafiltration) — Three liters of urine were pretreated with 4.3 grams of urease and mixed for 61 hours at room temperature. The digested urine was filtered through coarse filter paper to remove sediment and excess urease. Citric acid (143 gm) was added for ammonia neutralization.

Sample 24 (Ultrafiltration) — Three liters of urine were processed after being pretreated with 4.3 grams of urease, mixed for 66 hours at room temperature, filtered and 98 grams of citric acid added.

Samples 26 and 27 (Membrane Permeation) — The urine was processed without pretreatment.

Sample 33 (Ultrafiltration) — The urine (2.6 liters) was processed after being pretreated with 7 grams of urease, mixed for 64 hours at room temperature, filtered and 237 grams of citric acid added.

Sample 136 (Ultrafiltration) — This sample was processed in the same manner as sample 33 except that an unused membrane was installed in the recovery device.

Samples 138 and 139 (Electrolysis) — For each sample, 2 liters of urine were processed for 24 hours at 9 volts and 10 amperes. All values are approximate.

Sample 174 — This is distilled water (DW). It is included for comparison purposes.

Sample 175 — Urine was processed by electrolysis for 24 hours at 9 volts and 10 amperes then by ultrafiltration. The first process was intended to remove the organics; the second to remove the salts.

Sample 191 — This sample (TW) was taken from the fresh water tap of the Wright-Patterson water distribution system. It is included for comparison purposes.

Samples 194-196 (Electrolysis) — These were recovered from urine in the manner shown for samples 138 and 139. They were pooled then treated as follows:

Sample 194 — No treatment.

Sample 195 — Filtered up through a 6-inch long by 1-inch diameter column of 12 x 30 mesh pecan shell activated charcoal at approximately 3 liters per hour.

Sample 196 — Filtered through the pecan shell filter then through an ion exchange resin (Filter-Ion).

Samples 78 and 266-269 — These were recovered by electrodialysis.

Samples 249 and 250 — Urine was electrolyzed at approximately 9 amperes and 5-6 volts d-c for 24 hours and then forced (ultrafiltration) through a cellulose acetate membrane having a thickness of approximately 5 mils and a pore size of less than 1 μ .

ELECTRODIALYSIS — See table Ic.

All samples reclaimed by electrodialysis were recovered by a system purchased from Ionics, Incorporated (I). Effort was made to follow the operating instructions outlined by the manufacturer even though the early recovery attempts were frequently attended with mechanical and electrical difficulties. Following the recovery of sample 134, a fire in the base of the unit destroyed almost all of the electrical components making it necessary to return the device to the manufacturer for repair. Samples 266-269, table Ib were recovered after the reworked unit was delivered to AMRL.

The variations noted in the samples recovered were probably the result of differences in the composition of the urine processed and because of the residue which accumulated inside the stack. Samples 85 and 102 through 113 were recovered inside the AMRL Evaluator during one of several nutrition experiments conducted by AMRL for NASA (Houston). One liter of urine was processed during each run.

THERMOELECTRIC — See tables Id and Ie.

Urine processed by means of the thermoelectric distillation unit supplied by Whirlpool Corporation (W) was pretreated with 2 grams of trimethylol nitromethane (TN), with one iodine tablet (I) per liter of urine, or with 3.6 ml of a mixture of chromium trioxide, sulfuric acid, and distilled water. Each iodine tablet contained tetraglycine hydroperoxide and liberated 8 milligrams of iodine. Unless otherwise specified, the pretreatment used is indicated by (TN) or (I) at the end of the sample description.

In most cases, the product recovered by the thermoelectric device was forced through an internal charcoal filter to a water storage tank that was lined by a plastic bag. The water sample was drained from the storage tank. One liter of material was processed on each run.

Following is a discussion of the processing of the individual samples:

Table Id

Samples 38-41 — The water recovered on each run was not further altered. (TN)

Samples 42, 43, and 49-51 — These were recovered inside the AMRL Evaluator during a

nutrition experiment conducted for NASA, Houston. The urine was a mixture of that voided by the subjects and was 24-36 hours old when processed. Samples 42, 43, and 49 were pumped through a 0.15-micron filter. Samples 50 and 51 were from a 3-day pool of recovered water. Sample 51 was passed through a "Piodene" filter*. (TN)

Samples 97-99 — These represent the product produced on the dates indicated. For example, the product obtained on 1/20, 1/21, and 1/22 was pooled to provide sample 97. (TN)

Sample 100 — This sample was the residue from the vacuum trap of the distillation unit. It was, reportedly, of the same composition as samples 97-99 except that it has not been passed through the filter of the distillation unit.

Samples 101 and 117 — These were drawn from the storage tank of the distillation unit and are comparable in method of collection to samples 97-99. (I)

Samples 114-116 — These samples were, after being drawn from the storage tank of the distillation unit, filtered through a Millipore AP2004200 prefilter and a HAWP 0 47 00 filter (HA 0.45 μ). For sample 115, an S&S #595 filter was used ahead of the Millipore prefilter. (I)

Sample 118 — This sample was recovered from the residue in the vacuum trap of the distillation unit. It was filtered through the following: 2-inch long by 1-inch diameter column of activated carbon (Columbia Type C-64 Mesh 48-150), S&S #595 filter paper, Millipore AP2004200 prefilter, and Millipore HAWP 0 47 00 filter (HA 0.45 μ) in the order listed.

Samples 242-246 — These were processed without pretreatment and with the plastic bag of the storage tank and carbon of the filter removed from the distillation unit.

Table Ie

Sample 174 — Distilled water. Not processed in any manner.

Sample 135 — Obtained by processing distilled water drawn from the same bottle as was sample 174. The sample shows the elements that were added to the recovered water by the machine.

Sample 137 — This sample was obtained from urine following the processing of distilled water; i.e., sample 135. (I)

Samples 149-161 and 183-185 — The urine was pretreated, refrigerated overnight, and processed the next morning. Except as noted below, all samples were circulated for 15 minutes at 165 F (73.9 C) through a heat exchanger. (I)

Samples 183 and 184 — These were drawn from a 3-day pool of unheated recovered product. Sample 183 was then circulated for 15 minutes at 165 F. (I)

Samples 186 and 187 — These were obtained by processing atmospheric condensate collected inside the AMRL Evaluator during a 36-hour, 3-man heat test. The inside of the Evaluator was maintained at approximately 95 F (35 C).

Samples 189, 190, and 197 — The urine processed to obtain these samples was pretreated with 3.6 ml of a mixture of $\text{CrO}_3 + \text{H}_2\text{SO}_4 + \text{H}_2\text{O}$ per liter of urine.

NOTE: Samples 186, 187, 189, 190, and 197 were processed with the plastic bag of the storage tank and the carbon of the filter removed from the distillation unit.

*A 6-inch long by $\frac{1}{4}$ -inch diameter column of tetramethylammonium triiodide.

DEHUMIDIFICATION — See tables If, Ig, Ih, and II.

Condensate for the dehumidification samples except one sample, was collected inside the AMRL Life Support Systems Evaluator during a series of nutritional experiments conducted for MSC/NASA, Houston, Texas. Excess water in the atmosphere of the Evaluator was condensed by means of a heat exchanger and drained to a collector (aspirator bottle) from whence it is drawn directly or pumped through one or more filters.

All samples were stored in glass bottles and refrigerated at approximately 36 F until submitted to Taft Sanitary Engineering Center for analyses.

Details of the processing follow:

Table If

Sample 21 — This sample was recovered by means of a commercial home type dehumidifier located inside a room occupied by 4 subjects that were confined to the room for nutrition and pressure suit studies. Three days were required to collect the sample which was then filtered through a 0.15-micron filter. All components except the dehumidifier were sterilized prior to use.

Samples 28, 30, and 34 — These were not filtered or altered otherwise.

Samples 29, 31, 35, and 36 — These were filtered through a 0.15-micron filter.

Sample 37 — This sample consisted of ½ of sample 36 which was refiltered by means of a second 0.15-micron filter.

Samples 44-47 — The condensate was pumped from the aspirator bottle through a 0.15-micron filter and a 0.9-micron plus carbon filter in tandem.

Sample 48 — Not filtered. The sample was drawn directly from the collector.

Samples 52 and 53 — Filtered, pumped through a 0.15-micron and a 0.9-micron plus carbon filters in tandem, condensate collected over a 2-day period was pooled. Samples 52 and 53 were drawn from the pool. Sample 52 was filtered through a Piodene filter.

Table Ig

All samples were pumped through a 0.15-micron filter and a 0.9-micron plus carbon filter in tandem, unless otherwise noted.

Sample 54 — The sample was taken directly from the aspirator bottle and was not filtered.

Sample 61 — The sample was refiltered through Piodene filter.

Sample 64 — This sample is one-half of a mixture of two of the three lots of condensate collected during a 24-hour period.

Sample 65 — This sample is the remaining portion of the mixture from which sample 64 was taken. The sample was refiltered through Piodene filter.

Sample 66 — This sample represents the third or unmixed lot referenced under sample 64.

Samples 70, 73, and 75 — Each is a filtered sample to which one iodine tablet (tetraglycine hydroperchloride) was added. The iodine interfered with the analytical testing and very little data were obtained.

Sample 71 — The sample was taken directly from the collector and was not filtered.

Sample 77 — Water taken from condensate that had collected under the floor of the aft compartment of the AMRL Evaluator. It was not filtered nor treated in any manner.

Table I_h

Prior to the taking of samples, the heat exchanger upon which the water was condensed was washed and rinsed in tap water. The condensate filter system was sterilized with cryoxide gas (5 psig) prior to drawing samples 86-96 and was moved to the outside of the Evaluator after sample 96 was drawn. The air filter before the heat exchanger was changed after sample 92 was drawn. The condensate was taken directly from the collector or pumped through a 0.9-micron plus carbon filter and two 0.15-micron filters in tandem.

Samples 86-95 — These samples were filtered.

Sample 96 — This sample was not filtered.

Samples 119, 120, and 122 — These were pumped through the filters used for samples 86-95. The filters had been rinsed thoroughly in tap and distilled water then sterilized at 20 psig for more than 24 hours with cryoxide gas.

Sample 121 — Same as sample 122 except that it was unfiltered.

Samples 123-128 — These were pumped through new 0.9-micron plus carbon and two 0.15-micron filters that had been sterilized by autoclaving.

Sample 129 — This sample was drawn directly from the collector.

Table I_i

The condensate was drained into a collector from which it was pumped up through a 9-inch long by 4-inch diameter column of 48 x 150 mesh acid-washed carbon then through two 0.15-micron filters all in tandem.

Samples 142, 146, and 147 — These were not otherwise altered after being filtered.

Samples 179 and 180 — These were drawn from a pooled lot. Sample 180 was then circulated at 165 F (73.9 C) for 15 minutes. Sample 179 was not altered.

Other Samples — All samples other than those listed above were altered as follows. One liter of each was circulated at 165 F (73.9 C) for 15 minutes then poured back into the sample after approximately 25 ml were removed for testing.

OTHER TECHNIQUES

Samples recovered from dehumidification water collected inside the AMRL Evaluator are included with water recovered by means of fuel cells and by vacuum distillation. Details follow:

Table I_j

Samples 140-141 and 143-145 — These are unfiltered samples drawn directly from the aspirator bottle.

Sample 188 — This is an unfiltered sample of condensate collected during a 36-hour, 3-man heating capability evaluation (27 May 1965) of the AMRL Evaluator.

Sample 192 — This is unfiltered condensate from a 23 June 1965, 36-hour, 3-man heating capability evaluation of the AMRL Evaluator.

Sample 193 — This sample from the 23 June evaluation was filtered up through a 6-inch long by 1-inch diameter column of 12 x 30 mesh acid-washed pecan shell activated charcoal at the rate of 3 liters per hour.

Samples 200 and 248 — These samples were obtained from fuel cells of the type that were used during "Gemini" flights. Further data were not made available.

Sample 201 — This sample was reportedly obtained by vacuum distilling urine and passing the vapors through a low-temperature catalytic agent. The equipment and technique used were of a proprietary nature.

Samples 206-209 and 247 — All were recovered by vapor distillation. Except for sample 206, the vapors were passed through a 2-micron average pore size glass fiber cloth impregnated with porous "Teflon." For sample 206, nothing was inserted between the evaporator and the condensers. Temperatures at which the urine was evaporated were: Nos. 206 and 207 — 128 F (53.3 C), No. 208 — 100 F (37.8 C), No. 209 — 70 F (21.1 C), and No. 247 — 125 F (51.7 C). Pressures at which the evaporation occurred varied from 60 mm to 140 mm.

TABLE Ib
RESULTS - RECLAIMED WATERS

349

os. = Present in trace quantities
pt = Precipitate formed. No readout obtained.

* Major constituent
** Pooled samples may be 2 to 3 days older

TABLE Ic
ANALYTICAL RESULTS — RECLAIMED WATERS

— Domains [3 N] —

t = Precipitate form
= No data available

* Major constituent ** Pooled samples may be 2 to 3 days older
Pos = Present in trace quantities

TABLE I^d
ANALYTICAL RESULTS - RECLAIMED WATERS

卷之三

pt = Precipitate formed
= No data available

*D 11 11 11 11 11

*Pooled samples may be 2 to 3 days Neg. = Not detected

TABLE I
ANALYTICAL RESULTS - RECLAIMED WATERS

*Major constituent
**Pooled samples

$\sigma_{\text{opt}} = \text{Precipitate formed. No readout obtained.}$
 $\sigma_{\text{no data available}} = \text{No data available.}$

P_{pt} = Precipitate formed

TABLE II
ANALYTICAL RESULTS - RECLAIMED WATERS

Dotsbury & 4

- * Pooled samples may be 2 to 3 days older
Neg. = Not detected

— No data available
— Rejection level

TABLE 19
ANALYTICAL RESULTS - RECLAIMED WATERS

Do not blot #7

- *Pooled samples may be 2 to 3 days older

— No data available
— Projection based

TABLE I^b
ANALYTICAL RESULTS - RECLAIMED WATERS

12 TOTAL CARBON
**Pooled samples may be 2 to 3 days older
Pos. = Present in trace quantities
- = Precipitate formed. No residual obtainable.

- = No data available
- = Rejection level

1

TABLE II
ANALYTICAL RESULTS - RECLAIMED WATERS

*Pooled samples may be 2 to 3 days older/All dates are 1985

TABLE I
ANALYTICAL RESULTS - RECLAIMED WATERS

*Pooled samples may be 2 to 3 days older
*os. = Present in trace quantities

= Rejection level

SECTION IV. Conclusions

Considerable variations existed in the composition of water recovered from the same system from day to day. These were, usually, the result of variations in the raw material rather than in the water reclamation system or in the operation thereof. In most cases the recovered water met the requirements of the U. S. Public Health Service for drinking water. Where the standards were exceeded, the constituent level of the recovered water was within allowable limits for aerospace use. Often, the constituent level of water recovered from urine was less than that of the tap and distilled water tested. Trace metals were not a problem.

Condensate recovered from the atmosphere of the Life Support Systems Evaluator (LSSE) showed much higher chemical oxygen demand ratings than did water recovered from urine by a change of phase process. The high COD values were indicative of large quantities of oxidizable compounds. When organic materials were present, the problem of bacterial contamination was magnified. Passing the condensate through activated charcoal did not remove a substantial amount of the organics. Further study of charcoal types and contact time is needed.

Standards in addition to those listed by the U. S. Public Health Service for drinking water should be used in evaluating reclaimed waters. Weights for pH, conductivity, total carbon, ammonia, and bacteria should be included. Extensive testing of recovered water during aerospace missions is not feasible. Minimum standards, based on the capability of the recovery device should be established.

The data in tables Ia-Ij provide opportunity to study correlations between constituents or characteristics of the recovered water, i.e., trace elements vs conductivity or chemical oxygen demand vs total carbon. Sufficient data are available in many cases to permit the inference of a meaningful pattern.

Operation and evaluation tests revealed that thermoelectric, electrodialysis, and vapor compression water reclamation devices are suitable systems for use during an extended aerospace mission. The vacuum distillation water reclamation device, when used in conjunction with isotopes for supplying energy for vaporizing the waste liquid and for pyrolyzing the contaminants in the vapor, is considered the best system for aerospace application.

Appendix

SURVEY OF WATER RECLAMATION SYSTEMS

The reclaiming of potable water for aerospace use has been described in references 12, 13, 14, and 15. These describe in detail the sources from which the water can be recovered as well as the quantities needed for drinking, reconstituting foods, and for personal hygiene and sanitation. Also described are various processes for reclaiming water, with expected yields, power requirements, basic designs, and other pertinent information.

Data on reclamation systems that have been surveyed by the Aerospace Medical Research Laboratories and others are included in table II. Also included is the status of the systems studied and an AMRL rating of the systems for aerospace application. Systems that have been procured and operated by AMRL may be noted by the operating hours assigned.

The data in table II do not include penalties associated with power requirement nor are the systems reported on space optimized. Each system, except where vapors are pyrolyzed, requires both pre- and post-treatment.

Another and a more detailed analysis and comparison of the various candidate systems for recovering water during extended space travel was prepared by J. A. Steele, General Dynamics/Electric Boat (ref 31) for NASA, Langley Research Center.

TABLE II
WATER RECLAMATION SYSTEMS

System	Responsible Agent	Contractor	Reference	Volume (cu. ft.)	Weight (lbs.)	Watt-hrs/lb. of H ₂ O	Output lb./hr.	Recovery (%)	Operations (hrs.)	AMRL Rating	Status
1 Thermoelectric	AMRL	Garrett	16	1.2	65	>200	<0.2	<85	>85	NS	Complete
"	"	Whirlpool	17	3.5	49	146	1.0	<85	>270	A	"
"	"	"	*	-	-	-	-	-	-	-	Sep. 67
"	NASA	MRD	18	2	36	121	0.5	92	-	-	-
2 Electrodialysis	AMRL	Ionics	9, 10	1.4	50	100	0.9	85	73	A	Complete
"	"	Douglas	11	-	-	-	-	-	-	-	-
3 Ultrafiltration	AMRL	RAI	4, 5	-	-	-	-	-	338	B	Complete
"	NASA	"	6	-	-	-	-	-	-	-	"
4 Ultrafiltration—											
Electrolysis	"	"	7	-	-	-	-	-	-	C	-
"	AMRL	In-House	-	-	-	-	-	-	-	C	Dec. 67
5 Membrane Permeation	"	Ionics	8	2	128	400	0.05	85	>50	D	Complete
6 Freeze Drying	"	S. Un. of Iowa	19	-	>85	400	0.75	75	-	D	"
7 Electrolysis Cell—											
Fuel Cell	"	GE	20	1.6	67	65	0.4	98	-	C	"
8 Air Evaporation	NASA	Ham. Std.	21	12	100	375	1.44	98	-	B	-
"	AMRL	"	**	-	-	-	-	-	-	B	Sep. 67
9 Vacuum Distillation	"	MRD	22, 23	2.1	>35	0	0.6	98	-	D	Complete
10 Vapor Compression	"	"	1	3.4	60	108	1.2	91	>205	A	"
"	"	Elec. Boat	2	-	-	-	-	-	>94	NS	"
"	"	Gard	24	-	-	-	-	-	-	Jan. 67	
"	NASA	MRD	25	-	59	39	3	97	-	A	Complete
"	"	Marquardt	***	-	-	-	-	-	-	-	-
11 Vacuum Pyrolysis											
a. Electric	"	GE	26	-	-	-	-	-	-	A	Complete
b. Isotope	AMRL	"	27, 28	-	-	-	-	-	-	A	
12 Spray Condenser	"	Garrett	29	4.5	40	-	-	-	-	NS	Complete
13 Reiterative Freezing	"	Minneapolis Honeywell	30	-	-	-	-	-	-	NS	

NS = Not suitable

A = Leading

B = Promising

C = Extensive development required

D = Discarded

*AMRL Exhibit MRL-66-30, *Thermolectric Water Recovery System*.

**AMRL Exhibit MRL-66-112, *Water Recovery by Air Evaporation*.

***NASA Contract NAS 9-5119, *Waste Collection and Processing System*.

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13. ABSTRACT

Analyses were made of water recovered from human urine and from atmospheric condensate collected during manned tests inside a sealed chamber. Data on more than 200 samples were prepared for comparison with that of distilled water and tap water and with U.S. Public Health Standards for drinking water. Most of the samples were suitable for human consumption. Candidate systems for recovering potable water from urine were evaluated. Thermoelectric, electrodialysis, and vapor compression water reclamation devices were determined to be suitable for use during extended aerospace missions.

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